

HIGH-ENERGY ELECTRON AND X-RAY IRRADIATION AND CHARGING OF SPACECRAFT POLYMERIC MATERIALS

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This review discusses space-based and ground-based studies of the electrostatic charging properties of insulating polymers. In addition, the spontaneous discharging phenomena will be outlined because it is recognized as an unsolved problem on modern spacecraft capable of burning out integrated circuits and disrupting computer operations. Spacecraft polymers are exposed to severe radiation environments that are, in order of intensity: low-energy X-rays at the surface; high-energy electrons, high-energy protons, and high-energy photons within the spacecraft. Often, only high-energy electrons are studied because a) X-rays, gamma rays and bremsstrahlung simply excite high-energy electrons that cause the effects in polymers, and b) Proton flux is small enough to be ignored. Within the solar wind, direct irradiation by the Sun's emissions creates relatively low-voltage charging where performance of lightweight solar sails, thin film antennas and reflectors, and plasma spectrometers can be affected, while most other systems are unaffected.

The large particle currents carried by the solar wind interacting with planetary magnetospheres create trapped high-energy particle belts at Jupiter, Earth and Saturn where polymers become charged with internal fields exceeding electrical breakdown. Relative to space plasma potential, spacecraft bodies occasionally become charged to -20 kV, but frequently become charged to order -1 kV with a period coincident with the orbit. Space based measurements of polymer charging at the surface of spacecraft find potentials up to 10 kV relative to spacecraft body. The potential of charged polymers inside spacecraft has not been measured, but the frequent occurrence of spontaneous discharges indicates that order kV or more is attained.

Simple modeling, first extensively published by Gross et al, is sufficient to exhibit the important phenomena seen in laboratory tests over time-spans up to a day. Here, the high-energy electrons are stopped inside the polymer to generate space charge fields. At some field strength, the conduction processes remove charge as rapidly as high-energy electrons are stopped, and further buildup of field ceases. At radiation flux far exceeding space level, the field strength has been measured up to 3×10^6 V/cm in PMMA, far exceeding breakdown, and inducing measurable high-field enhanced conduction. Field-induced tunneling of electrons into "conduction band" is observed, along with deflection of the high-energy electron trajectories inside the PMMA. Many polymers experience breakdowns in ground irradiation tests. Electrostatic fields internal to polymers have not been measured in space, but occurrence of spontaneous discharges provides evidence that fields exceeding 1×10^5 V/cm are routinely achieved.

Results in space appear to be strongly controlled by conduction processes and other processes in polymers. Conduction can remove charge almost as fast as it is injected by space radiation, and it is difficult to predict if charging problems will occur. But after months in space the conduction processes change by up to three orders of magnitude, and charging effects can be more or less severe depending on the material. Conduction in Kapton and Teflon is enhanced over time in space radiation, but is decreased in epoxy and nylon. After exposure to radiation and vacuum for months, spontaneous discharge frequency in epoxy circuit board material can be used as a measure of space radiation intensity. Spontaneous discharge frequency in Teflon circuit board is significant only for the first few months in space. The frequency and amplitude of the discharge pulses is also dependent upon the geometry of metal electrodes on the polymer because interface processes and conduction processes strongly modify the electric field. Ground tests find pulses from circuit boards and connectors that are sufficient to burn out integrated circuits.